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OH-58 Pilot Display Unit (PDU) Simulated Crash Tests

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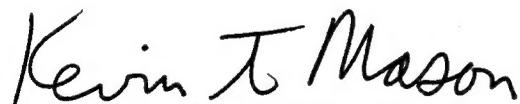
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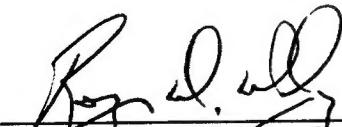
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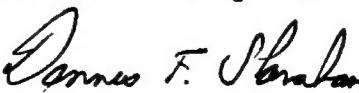
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Introduction

The pilot display unit (PDU) is designed to be placed on the right (pilot's) side of the OH-58 helicopter to provide visual targeting and a missile status display. The location of the PDU (directly in front of the pilot's face) and the 7-pound mass of the unit potentially creates a hazardous head impact surface in some accident scenarios. Computer model studies by Bell Helicopter Textron (BHT) showed the potential existed for head injury in accidents as discussed at an in-process review (IPR) of the PDU at BHT. Contact of the pilot's helmet to the PDU also was noted by the U.S. Army Aviation Developmental Test Activity (ADTA) in 1987 as shown in their documentation photograph (Figure 1).

Subsequent to the 1987 IPR, the PDU program manager (PM) contracted with BHT to design and "drop test" a new breakaway mechanism to permit the 7-pound PDU to "break free" during a crash and move forward 3.5 inches along a track. In early 1988, the PDU PM and the U.S. Army Aeromedical Research Laboratory (USAARL) mutually agreed a suitable "crash" could be simulated with the surplus OH-58 fuselage which Aviation Systems Command (AVSCOM) had procured for use in crash testing the OH-58 retrofit pilot's seat (Haley and Palmer, in press). The testing scheme used the damaged front cockpit salvaged from an OH-58 mishap. Arrangements were made with the Federal Aviation Administration's (FAA) Civil Aeromedical Institute (CAMI) to conduct and document the crash tests.

Initial plans, stated by the PDU PM, called for BHT to supply a suitable dummy PDU test item and an OH-58 cockpit test fixture, and to monitor the crash tests. USAARL agreed to direct the crash tests, analyze the data, and provide a test evaluation report. This report fulfills the agreement.

PDU description

The unit as installed in the OH-58 helicopter is shown in Figures 1 and 2. The PDU is designed to break free at a deceleration of 2 G from the normal (flight) position, move forward and downward to the end of the slotted track, as shown in Figure 3. The prototype PDU was "drop" tested at the BHT facility in 1987 and the unit slid forward properly at 2 G deceleration (Powell, 1988). The PDU mount is detailed in BHT drawing 206-071-280-105.

Test objective

To determine the effects of the OH-58 dummy pilot impacting against the new PDU during simulated crash conditions.

Materials and test methods

The surplus damaged OH-58 fuselage is shown installed on the CAMI impact sled and track in Figure 4. The sled is mounted on rollers and is accelerated along two tracks by a cable passing through several rollers and attached to an elevated mass. The decelerative "crash" is provided by sled contact with $\frac{1}{4}$ -inch diameter steel wires which are pulled around rollers anchored in the floor. The decelerative pulse shape is varied by the total number of wires and their placement along the track.

The OH-58 honeycomb belly "bathtub" was cleanly severed just forward of the troop seat and the roof was cut through just forward of the transmission mount (Figure 5). The pilot seat bulkhead with shoulder strap guides and the upright center "box" beam were left intact. The forward fuselage then was rigidly mounted to a horizontal "crash" sled with a belly-mount structure which could be oriented to provide the desired crash force vector. The intent was to conduct six to eight crash tests up to a 28 G level without causing irreparable damage to the forward fuselage. Thus, instrumented "dummy" pilots could be installed in the sled-mounted fuselage, and crash vectors applied to the sled so both the crashworthy seats and the PDU head injury potential could be evaluated with the same fuselage in a single test series.

BHT prepared a dummy PDU test specimen and mount for the OH-58 test cockpit as shown in Figure 4. The dummy PDU was located the same as the actual device would be after "breakaway," i.e., 3.5 inches forward down the 29-degree slope ramp as shown in Figure 3. The dummy PDU was constructed to simulate the actual PDU adjusted 1 inch down from the "full-up" adjustment; thus the test was conservative because the eye height of the 50th percentile dummy actually was 0.27 inch higher than would be normal in most standard plastic mesh seats with the buttock reference point (BRP) at waterline (WL) 32.73 in lieu of WL 33.0 on the test crashworthy seat. The extra 0.27 inch represents a 59th percentile eye height for an upright pilot (Donelson and Gordon, 1991). However, the usual slumped flying posture indicates this would be an 83rd percentile pilot in slumped posture (slump subtracts approximately 0.9 inch). In any event, the test was conservative because a large percentile dummy eye height was used with the PDU adjusted down 1 inch for a small pilot so that a PDU strike was more likely to occur.

The test conditions for the five sled runs conducted to evaluate the PDU's crash performance are shown in Table 1. The first test (CAMI 88060) was selected to simulate a SOM-LA modeling analysis (Laananen, Coltman, and Bolukbasi, 1982) done by BHT. The second test (88061) repeated the first except the velocity of impact was increased along with the onset rate. The third test simulated a pure longitudinal (x-axis) impact. The fourth and fifth tests (88063 and 88064) were similar to the third test except 15 degrees right yaw was added and the velocity change was increased. These "crash" simulations were selected after conferences with the U.S. Army Safety Center (USASC) and AVSCOM. The consensus was the impact energy and stopping force (peak G) used in these tests were near the limits of a survivable crash for the OH-58 structure.

The 50th percentile Hybrid III dummy occupied the right seat for all five PDU tests, and the 95th percentile VIP dummy occupied the left seat for the first three tests only. The large VIP dummy primarily was used for testing convenience, to prevent recalibrating the $\frac{1}{4}$ -inch diameter steel rods used to stop the sled during the prior crashworthy seat tests. The large dummy also was used to provide comparative test data between the 50th and 95th percentile dummies and to note whether the dual-mode (1.5 G lock) reel (used in the left seat) was reliable and effective. The test instrumentation is listed in Table 2.

The inertia reels of both "dummy" pilots were set to the unlocked condition to ensure conservatism. The unlocked reels would permit more strap movement before stopping the torso.

Film motion analysis

Film footage of PDU tests was analyzed on a NAC™ model PH-160F* film motion analyzer. The lower left corner of the image was considered to be the origin ($x=0$, $y=0$). A background strobe light signaled the beginning of each impact sequence. The frame in which the light came on was considered to be the first frame for each impact sequence. A scaling factor was calculated for each impact sequence by obtaining coordinates for the top and bottom of the fuselage (rear most area) and the absolute distance between these two standard points was determined. The actual distance from the top to the bottom of the fuselage then was divided by the absolute distance to give the scaling factor. Since the camera was located approximately 50 feet from the sled, no correction was made for the minimal parallax involved.

* See manufacturer's list

Table 1.
OH-58 PDU test conditions.

| Test identity | Sled velocity (fps) | Cockpit orientation on test sled | Applied pulse (G - sec) | Hybrid III Dummy description (50th% size) -right seat- | Remarks |
|--|---------------------|-------------------------------------|-------------------------|---|--|
| CAMI 88060 pitch down zero yaw zero roll | 23.5 | | | Hybrid III with neck & Lumbar load cells + Triax accelerometers in head & chest-flight suit, med. size helmet & leather boots | * Replicates Somalia analysis |
| CAMI 88061 same as 060 | 28.3 | (same as 060) | | (same as above) | |
| CAMI 88062 forward (X-axis) only | 30.4 | | | (same as above) | Rt. dum. moved fwd. 1.5" to ensure PDU impact |
| CAMI 88063 forward with 15° rt yaw | 35.5 | (same as 062 + 15° yaw to right) | | (same as above) | Actual PDU "breakaway" track installed |
| CAMI 88064 same as 063 | 35.8 | (same as 063) | | (same as above) | - Actual PDU "breakaway" track installed - Rt. dummy moved fwd. 1.5" and Rt. by 1.5" to insure PDU impact |

Table 2.
Instrumentation for PDU testing.

- Sled X (resultant acceleration (G)
(two each used for reliability)
- 50th percentile (Hybrid III) dummy transducers
 - Head x, y, z accelerometers and xyz resultant calculation
 - Chest x and z accelerometers
 - Spinal column load cells in right seat dummy
Neck x, y, and z force, and moment about x, y, and z
axes
 - Lumbar x, y, and z force, and moment about x, y, and z
axes
- Right helmet movement (Celesco rotary potentiometer*)
(5 G extraction limit caused gross error)
- Right side profile camera at approximately 50 feet distance
(1000 frames/sec)
- Right side profile camera at approximately 35 feet distance
(500 frames/sec)
- Left side profile camera at approximately 35 feet distance
(500 frames/sec)

Notes:

- (1) Ektachrome reversal, type 7250, EP400 film*
- (2) The filtering used for all transducers met the requirements of Society of Automotive Engineers J211 report, "Instrumentation for impact test." Pertinent requirements are listed:

| <u>Instrument</u> | <u>Frequency response channel/class</u> |
|---|---|
| CAMI sled accelerometers, lumbar and neck load cells, and rotary potentiometers | 60 |
| Chest and pelvis accelerometers | 180 |
| Head accelerometers | 1000 |

Coordinates were obtained for the helmet reference point directly over the dummy's ear, the PDU, targets on door frame, and in some cases, for the point where the restraint harness was attached to the seat back. Data were entered into a database which later was used with a graphics program. Graphs depicting the displacement of the helmet reference points were generated for each sequence. Helmet reference point velocity was calculated using the distance between each point divided by the time increment (the time was based on film speed).

Helmet rotation was determined by tracing the outline of the helmet at various times during the impact sequence and measuring the angle of the helmet brow line in relation to the bottom of the fuselage. Helmet rotation then was plotted on the helmeted head displacement curves.

Test results

The PDU tests were conducted at the FAA CAMI test center, Oklahoma City, Oklahoma, 22-24 June 1988. The tests were done subsequent to the three OH-58 crashworthy seat tests (88057, 88058, and 88059) which were completed 17 June 1988. The OH-58 cockpit structure and broken crashworthy seats were mended and strengthened sufficiently to keep the cockpit structure intact and to simulate the stiffness of the PDU mount area during a crash.

The test results are summarized in Table 3. The more important transducer traces between the five tests are copied and compared in the Appendix, Figures A-1 through A-4. Traces not present in this report would not have provided significant data, and were deleted to save the cost of preparation and printing. Data not presented is available from USAARL's archives, if desired.

Table 3 includes PDU mount type, PDU displacement, helmet impact, and dummy neck/moment data. The head acceleration values are not presented because all the values are less than 60 G and not significant. The neck force and neck moment about the lateral (y) axis are significant and are shown in Table 3; the traces are shown in figures A-1 through A-4. The neck forces and moments do not exceed the tolerance limits noted by Alem and Haley (1988).

The movement of the right pilot's helmeted head was determined by film analysis and is shown to one-quarter scale for all five runs in Figures 27 through 31.

Table 3.
Summary of PDU test results*.

| Test identity | Sled velocity (fps) | Sled peak deceleration (G) | Actual PDU breakaway mount used? | PDU mount actuation? | Helmet to PDU contact (impact) | Dummy neck resultant force (lb) | Dummy neck movement about Y-axis (in-lb) |
|--|---------------------|----------------------------|----------------------------------|----------------------|--------------------------------|---------------------------------|--|
| CAMI 88060 pitch down zero yaw zero roll | 23.5 | 15 | no | not applicable | yes very light | 444 | 613 |
| CAMI 88061 same as 060 | 28.3 | 19 | no | not applicable | yes light | 579 | 1195 |
| CAMI 88062 forward (X-axis) only | 30.4 | 19 | no | not applicable | yes moderate | 424 | 679 |
| CAMI 88063 forward with 15° rt yaw | 35.5 | 16 | yes | yes | no | 691 | 1150 |
| CAMI 88064 same as 063 | 35.8 | 16 | yes | yes | yes moderate ** | 488 | 803 |

*Head accel, neck force/mom. pelvic force/mom. & chest accel are located at A-1 to A-4.

**PDU mount at windshield frame failed partially during rebound, see Fig 24.

Test 88060

The setup for test 88060 is shown in Figure 4. As shown in Table 1, this test simulates a pitch down crash in which the vertical force is slightly greater than half the forward force. At 500 G/sec acceleration onset and 15-G peak combined with only 23.5 fps velocity, the impact was of moderate level. As shown in Table 3, the neck tensile force of 444 pounds and 613 inch-pound moment about the lateral (y) axis is about half that of the values in test 88063. The force transfer into the PDU $\frac{3}{4}$ -inch ENSOLITE™* foam from the helmet impact did not register on the neck load cell or the head accelerometers.

The movement of the helmeted head of the left dummy was recorded by a Celesco potentiometer as shown in figure A-5. The recorded 26-inch value obviously was incorrect based on a cursory film review; the film analysis revealed a movement of 13 inches, half that shown by the potentiometer. Note in Figure A-5 the film showed about 1 $\frac{1}{2}$ -inches of movement before the potentiometer began to rotate (record), and the potentiometer continued to record movement from 15 to 26 inches between 150 and 200 ms. Thus, it is clear the potentiometers on both dummies cannot be used for precise movement data. Discussions with the CAMI test track chief, Mr. Gowdy, indicate the acceleration of the cables from the instruments exceeded the rate limitations of the device. Nonetheless, the first four recordings from the right dummy's helmet are copied and compared in Figure A-2, and all show a similar "overrun" error from 21 to 29 inches. The actual helmeted head movement in all five tests shows movement of 12 to 14 inches. Thus, the film analysis motion is used exclusively in discussing helmet movement in these tests.

Posttest photos of test 88060 in Figures 4 through 9 show: (a) rotation of helmet rearward on right dummy, but not the left dummy, even though both have equal size 50th percentile heads; the difference may be due to the lack of neck flesh on the Hybrid II (50th percentile) dummy; and (b) the left seat crashworthy seat pan sustained enough downward force from the dummy's buttocks to move the pan down 0.6 inch, and to move the right seat down by 0.3 inch. This was a surprise since the impact vector was 15 G forward, and the seat pans stroke at 12 G vertical. The right seat pan was secured with steel straps to prevent movement in subsequent tests.

Test 88061

The setup is shown in Figure 10, the straps to secure the right seat are shown along with the reinforcement of the left forward door bulkhead. The posttest photo is at Figure 11.

Review of the helmet's movement in Figure 28 shows almost identical movement to the prior test (approximately 13.8 inches in this test, and 13.7 inches in 88060). One would have expected more movement with greater energy and peak G in the sled pulse. It may be the inertia reel locked sooner in the pulse sequence and prevented as much shoulder strap extension. For some unknown reason, the dummy's helmeted head moved downward nearly 6 inches in lieu of 2.1 inches in the identical test 88060; this down movement caused the helmet to almost miss the PDU with only grazing contact. No marks could be seen on the helmet visor cover and no contact is shown by film analysis in Figure 28.

Reference to Table 3 shows the neck moment to be twice as much as in the test 88060; thus neck moment correlates with the head movement. Probably the greater energy of the vertical force component caused the head-helmet mass to bend the neck much further downward and forward than in the prior test.

The left seat pan stroked down to 3 inches at the pan's rear, but no action was taken to prevent stroke to the left seat.

Test 88062

In this pure longitudinal x-axis test, the likelihood for PDU impact is greatest. The right dummy was placed 1.5 inches forward in the seat by use of a wooden spacer between the dummy and the seat cushion as shown in pretest Figures 12 and 13. Damage to the aircraft structure is documented in Figures 14 through 18.

In spite of greater energy in this test over 88061, the right dummy's neck force and moment were little greater than the first test (88060), as shown in Table 3; the apparent anomaly is explained partially by the lack of a vertical impact vector in this test. However, reference to Figure 29 shows contact between the helmet and PDU at about 135 ms. Simultaneously, the movement in the neck about its lateral (y) axis also changes slope and becomes a constant level at just over 600 inch-pounds for the next 40 ms as seen in Figure A-2. In this time span between 135 and 175 ms, interpretation of Figure 29 shows the helmet's energy being reduced by: (1) foam compression, (2) inertial force against the PDU, (3) structural deformation of the PDU mount, and (4) sliding friction caused by 3 to 4 inches relative movement. Thus, it is highly probable the neck moment would have been much greater, perhaps twice as great if the helmet-PDU impact did not occur.

This test is a moderate level impact even though the film shows the PDU moving about 2 inches up and 2 inches forward on

the elastic PDU mount. the "moderate" impact description pertains to the insignificant change in the acceleration of the head as shown in Figure A-1; note the head deceleration peaked at 105 ms and reduced to approximately 10 G, and did not sustain a greater value for the remainder of the pulse. Thus, the absence of significant head deceleration and neck moment provides a noninjurious "safe passage" for the dummy pilot through this crash scenario.

The helmet was replaced after this test due to permanent foam compressive "set" of about 0.05 inch over an area of about 1 square inch in the lower front edge of the foam liner. The foam replacement is required to obtain the full energy-absorbing benefit of the foam liner if impacted again at the same location. The impact location onto the PDU is shown in Figure 15.

The fuselage station (FS) 73.04 bulkhead was damaged by skin crippling/buckling at the lower outboard edges and at the control "closet" box structure as shown in Figures 16-18. The bulkhead was reinforced prior to the final tests.

Test 88063

To fully explore the potential crash vector envelope, the forward vector was changed to include a 15-degree right yaw and the impact energy (velocity) was increased to 35.5 fps. In addition to the impact vector change, the actual PDU "breakaway" mount with track was used with the PDU in the normal "IN-USE" position. The IN-USE position is 3.5 inches rearward and about 1.5 inches upward from the breakaway (crash position). The actual PDU mount may be seen in pre- and posttest Figures 19 and 20 which also show the cockpit reinforcement and the 50th percentile dummy with hands on the cyclic control. Note in Figure 20 that the PDU moved forward and down during impact to the breakaway location.

The right dummy pilot was moved 1.5 inches forward by placement of a wooden block in the seat back as in test 88062. Also, the 95th percentile dummy was removed from the left seat in order to lessen the restraint harness loads acting on the FS 73.04 bulkhead for the final tests.

The test was successful in that the PDU moved forward and downward along the twin track, as designed, prior to the helmeted head entering the space; thus, no PDU-helmet impact occurred. The helmeted-head movement from film analysis is at Figure 30; a slight correction due to the 15-degree yaw was needed. The camera was located at right angles to the sled path, but skewed 15 degrees to the cockpit's motion so the distance moved by the

helmet was 3 percent greater than recorded from the film (the maximum correction was: 12.5 inches \div COS 15 degrees = 12.9 inches).

The transducer data are shown in Figures A-1 through A-4. The head deceleration peaked at 48 G, the highest of all five runs, but well within human tolerance. The moment load on the upper neck peaked at 1150 inch-pound (see Table 3) and Figure A-2), but less than the 1195 foot-pounds seen in test 88061. Again, this value is within human tolerance as noted in Alem and Haley (1988).

Test 88064

This test was a repeat of test 88063 except the dummy was moved forward 1.5 inch by placing a wooden block behind it and to the right by 1.5 inch by simply sliding the dummy to the right, flush against the lap belt inner surface (Figure 21). In addition, an 0.05 x 1.5-inch aluminum strap was added to the right door opening as shown in the same figure. This strap was intended to reduce elastic deflection of the upper door post.

Helmet to PDU impact occurred; Figure 31 shows the impact from film analysis. The impact appeared to be severe based on film review since the PDU mount failed at its leading edge rivet attachment to the windshield overhead frame, as depicted in Figures 23, 24, and 26. The impact cracked the helmet visor cover at its center low edge, as shown in Figure 25. The PDU foam also was cracked and the visor cover released the visor knob and visor.

In spite of the damage to the mount and a fracture of the helmet visor cover, the neck force and moment values are less than those recorded in test 88061. Again, the neck transducers show a change in slope of the force and moment curves at approximately 105 ms, the time of the initial helmet impact, and the peak values were less than the prior test where the helmet did not impact the PDU. It is evident that helmet impact against the PDU tends to lower the force and moment in the neck caused by inertial force. Since the helmet prevents excessive head deceleration (from PDU impact), the PDU is not considered a hazard for helmeted pilots.

Conclusions

The PDU device breaks free and slides forward out of the path of a flailing head for most crashes. For those crashes in which helmeted-head impact occurs, peak deceleration of the head

is not excessive, and neck forces and moments are within tolerable limits.

Under the simulated crash conditions, the PDU unit tested does not cause injuries to helmeted pilots. This statement assumes the use of a properly-fitted SPH-4 helmet.

References

Alem, Nabih M., and Haley, J. L., Jr. 1988. Assessment of human tolerance based on Hybrid III transducer readings. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL White paper for use by TACOM.

Donelson, Sarah M., and Gordon, Claire C. 1991. 1988 anthropometric survey of U.S. Army personnel: Pilot summary statistics. Natick, MA: U.S. Army Natick Research, Development and Engineering Center. NATICK TR-91/040.

Haley, J. L., Jr., and Palmer, Ronald W. 1994. Evaluation of a retrofit OH-58 pilot's seat to prevent back injury. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. In press.

Laananen, D. H., Coltman, J. W., and Bolukbasi, A. O. 1982. Computer simulation of an aircraft seat and occupant in a crash environment, volume II, Program SOM-LA user manual. Atlantic City Airport, NJ: F.A.A. Technical Center. DOT/FAA/CT-82/33-i.

Powell, David. 1988. Air-to-air stinger pilot's display unit mount assembly, drop test, test results. Fort Worth, TX: Bell Helicopter Textron. Bell Report No. 206-091-062.



Figure 1. Left side view of PDU installation, breakaway position shown.



Figure 2. Front view of PDU installation, normal in-use position shown.

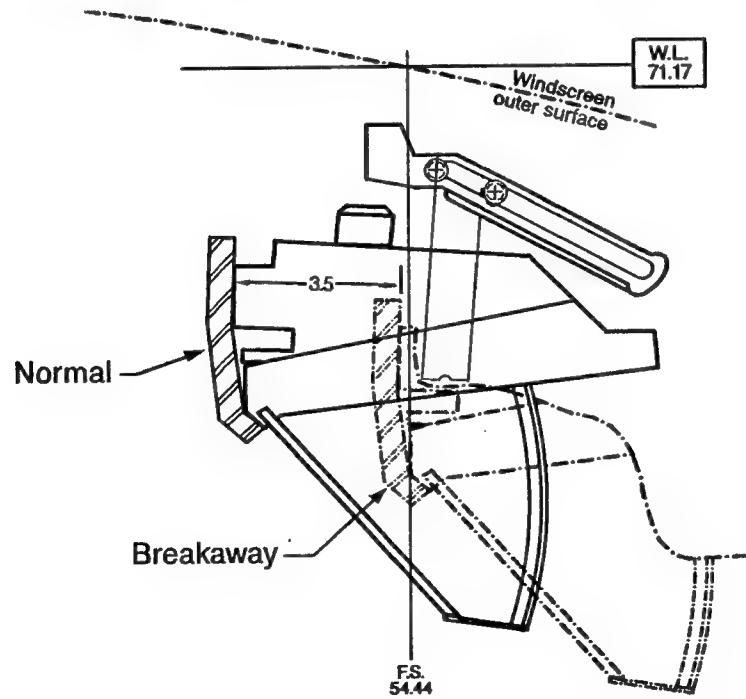


Figure 3. Profile sketch of PDU location in OH-58 cockpit showing the normal and crash breakaway position.

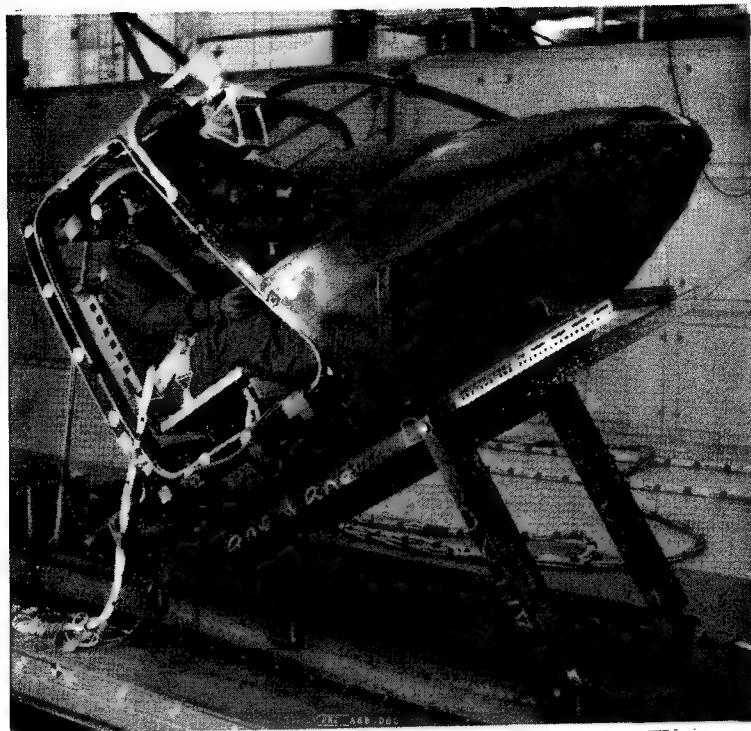


Figure 4. Pretest view of no. 88060; note the absence of crashworthy seat cushion and the dummy PDU and mount.

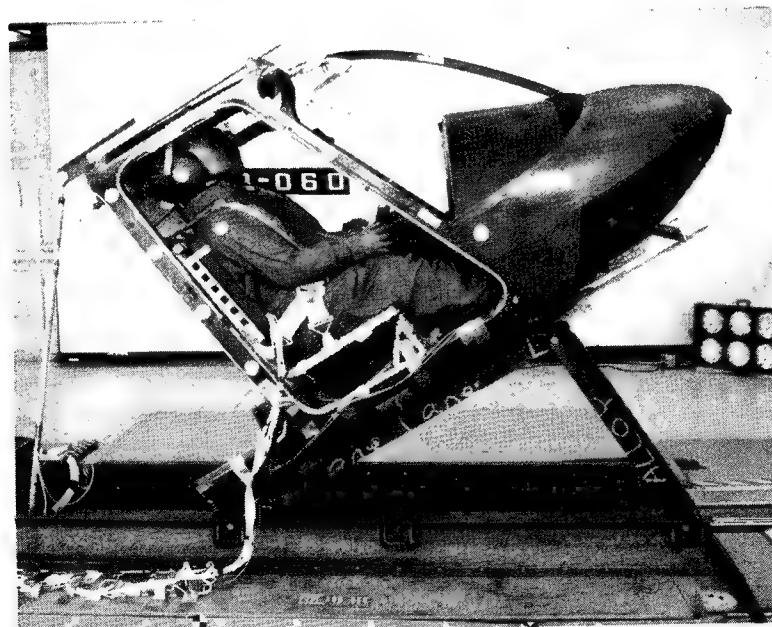


Figure 5. Posttest view of no. 88060; note the rearward rotation of helmet after rebound.

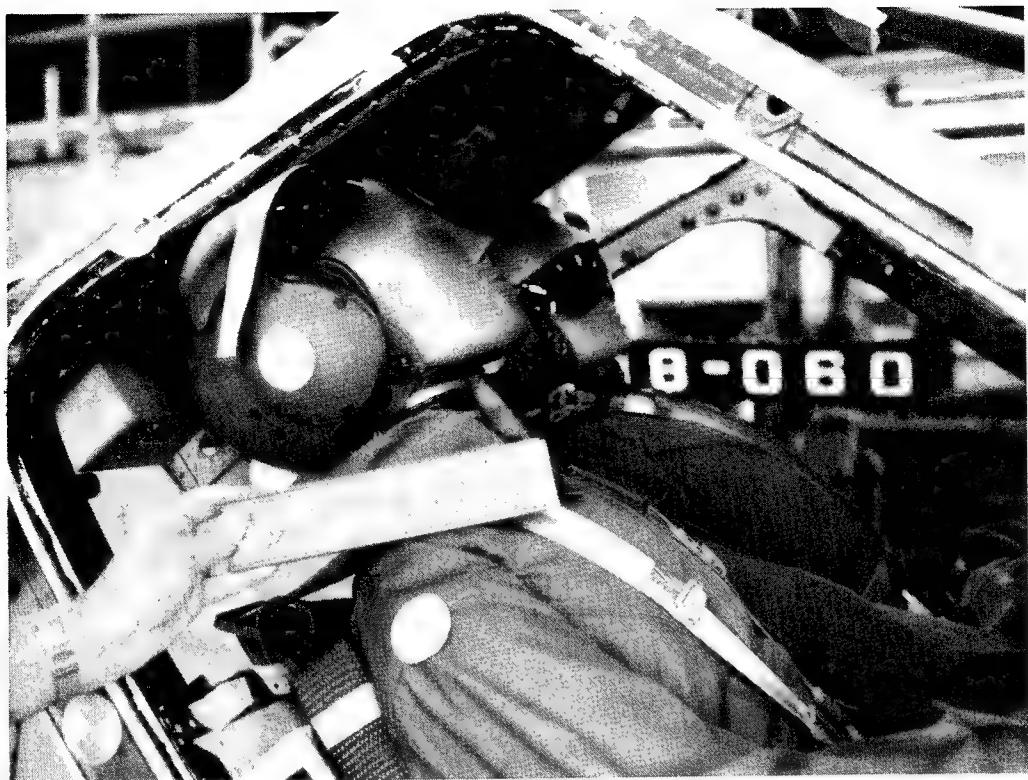


Figure 6. Posttest view of 50th percentile dummy; note helmet rotated until stopped by nape strap.

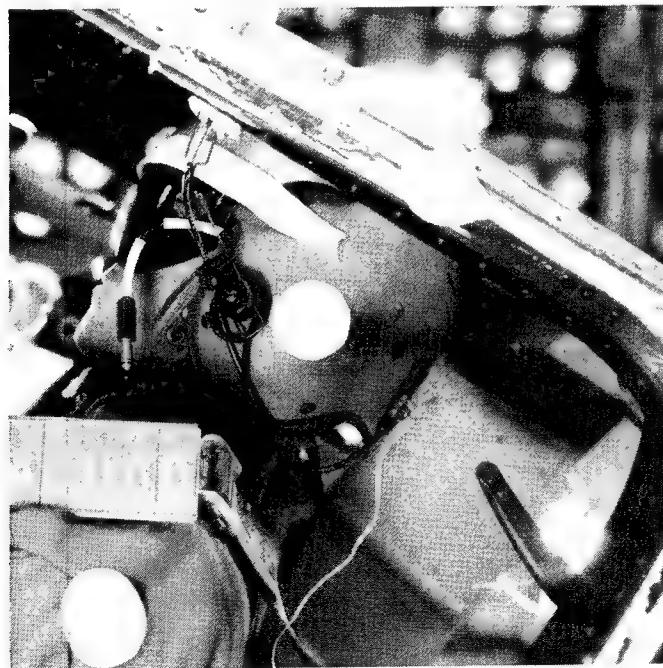


Figure 7. Posttest view of 95th percentile dummy in left seat.

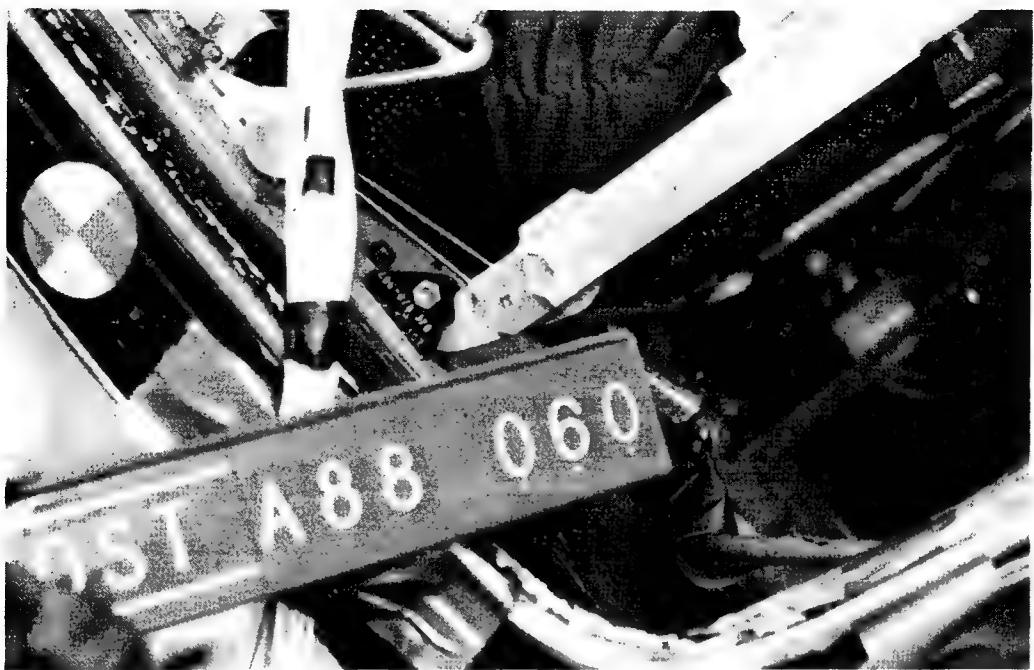


Figure 8. Seat pan downward displacement of 0.3 inch shown between latch and bulkhead support, right side.

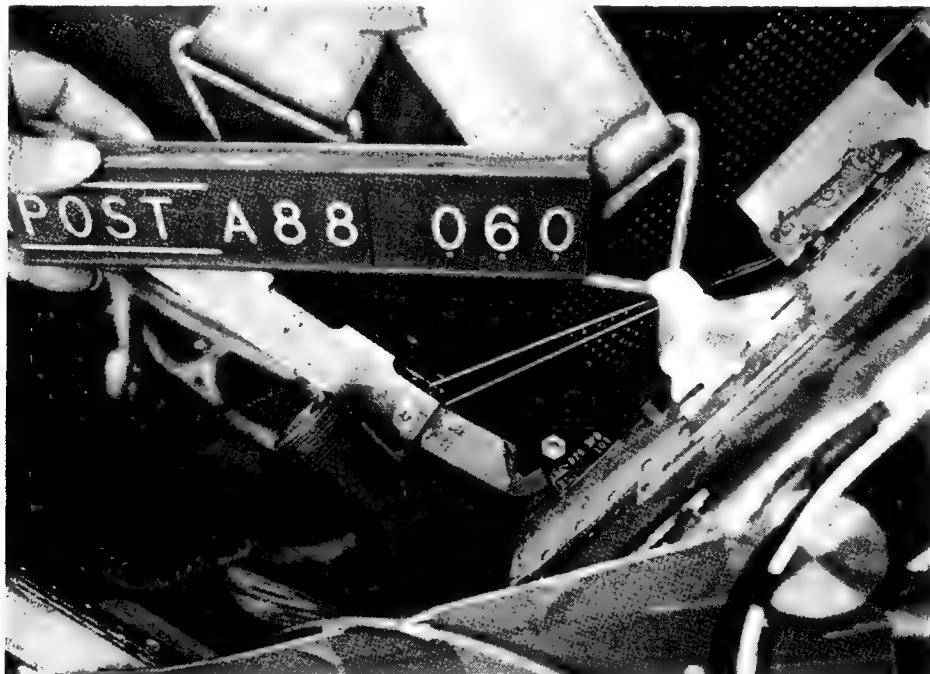


Figure 9. Seat pan downward displacement of 0.6 inch shown between latch and bulkhead support, left side.

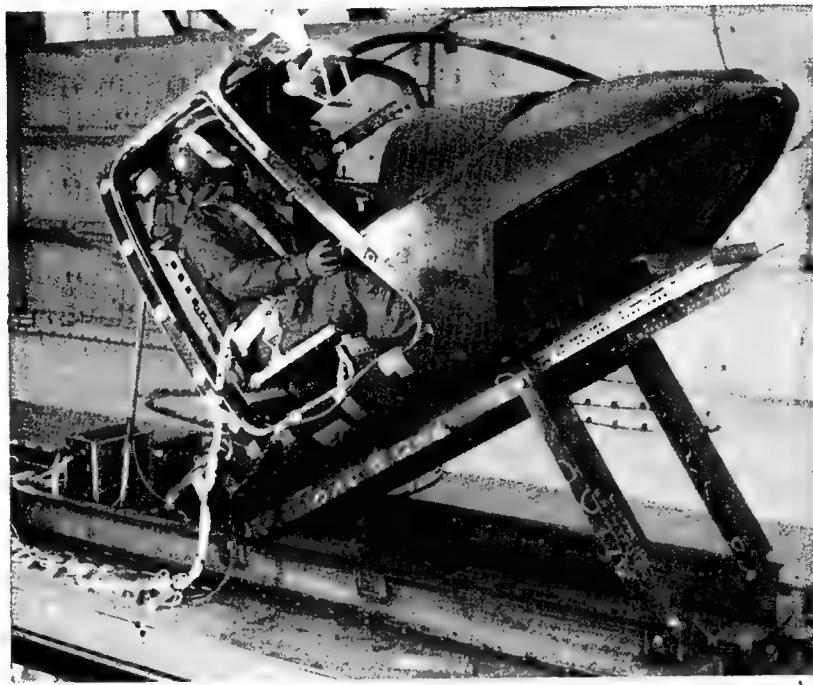


Figure 10. Pretest view of CAMI 88061; note aluminum strap on inside of left door frame and steel strap on right seat.

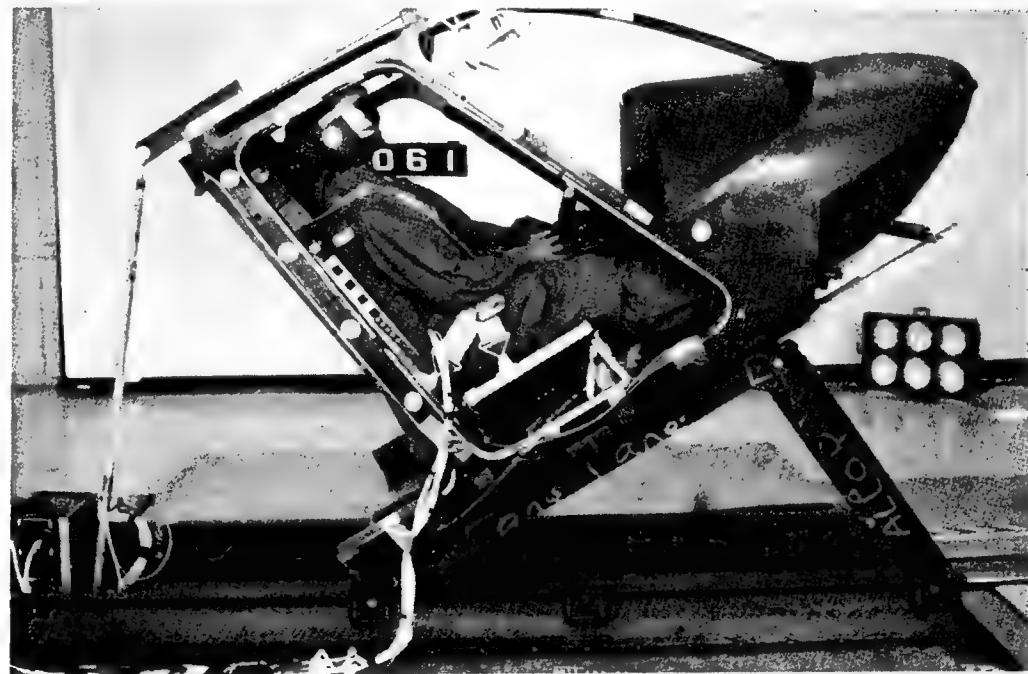


Figure 11. Posttest view of CAMI 88061; note that helmet has not rotated due to tape under chin.

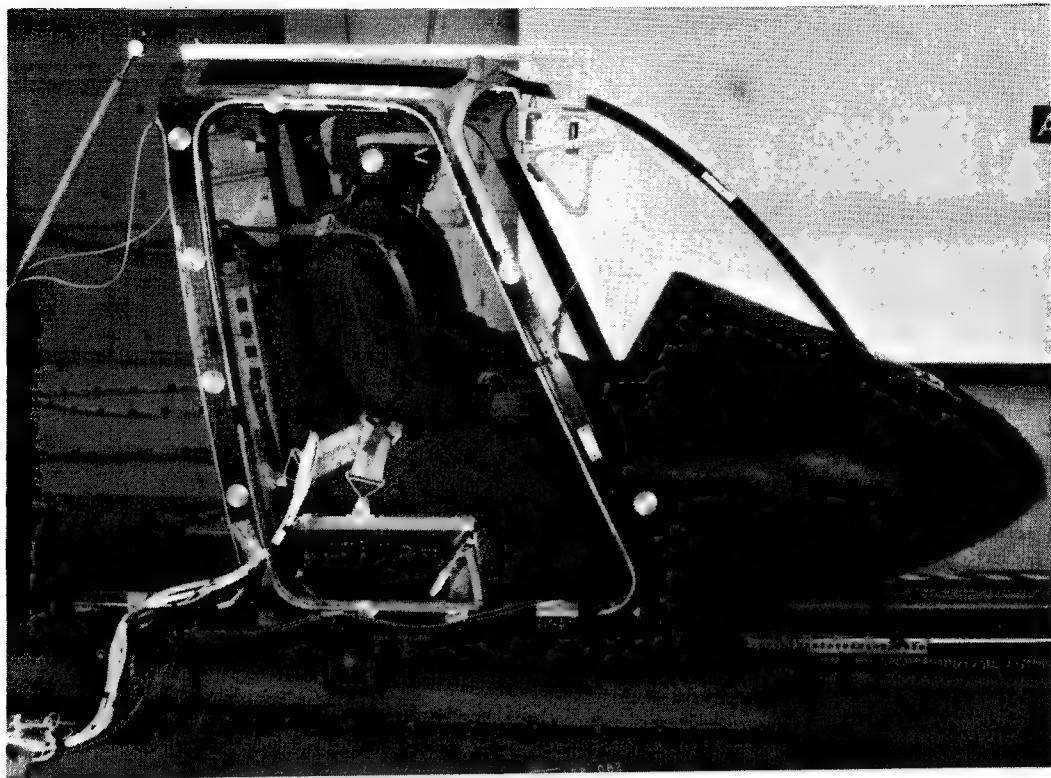


Figure 12. Pretest of no. 88062; note potentiometer cable attached to back of helmet.



Figure 13. Pretest view of no. 88062; note board placed at back of seat to place right dummy 1.5-inch forward.



Figure 14. Posttest view of no. 88062; note rebound position of sled about 1 foot from displaced $\frac{1}{4}$ -inch diameter cable.

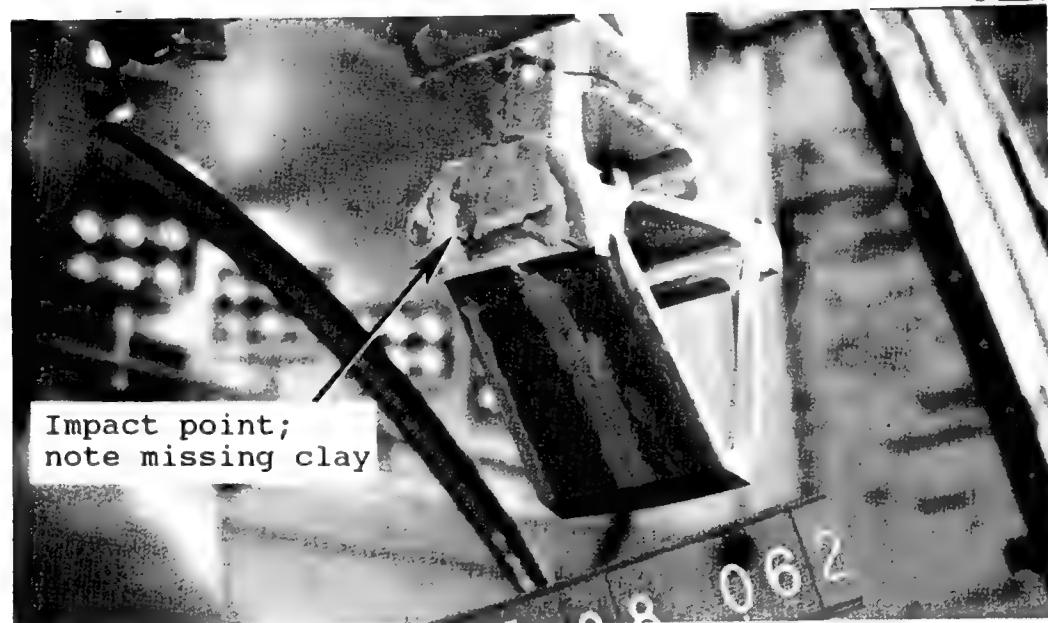


Figure 15. Posttest view of no. 88062; note missing clay which was found on helmet of right dummy.

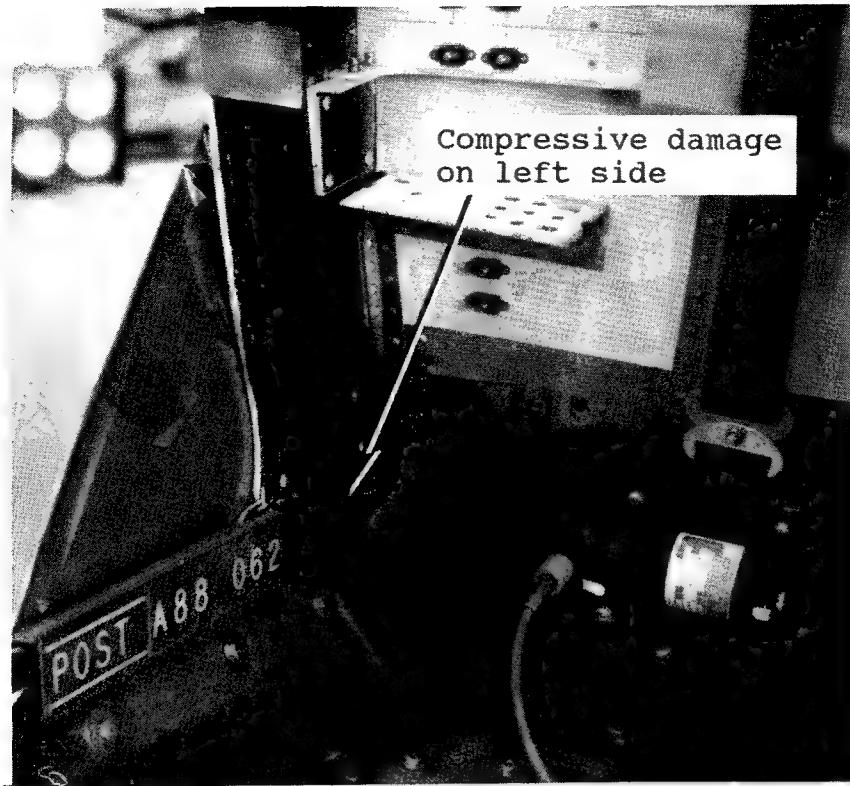


Figure 16. Posttest of no. 88062; note buckled "box" section of fuselage station 73.04 bulkhead.



Figure 17. Posttest view of no. 88062; note buckled skin adjacent to "box" section of fuselage station 73.04 bulkhead.

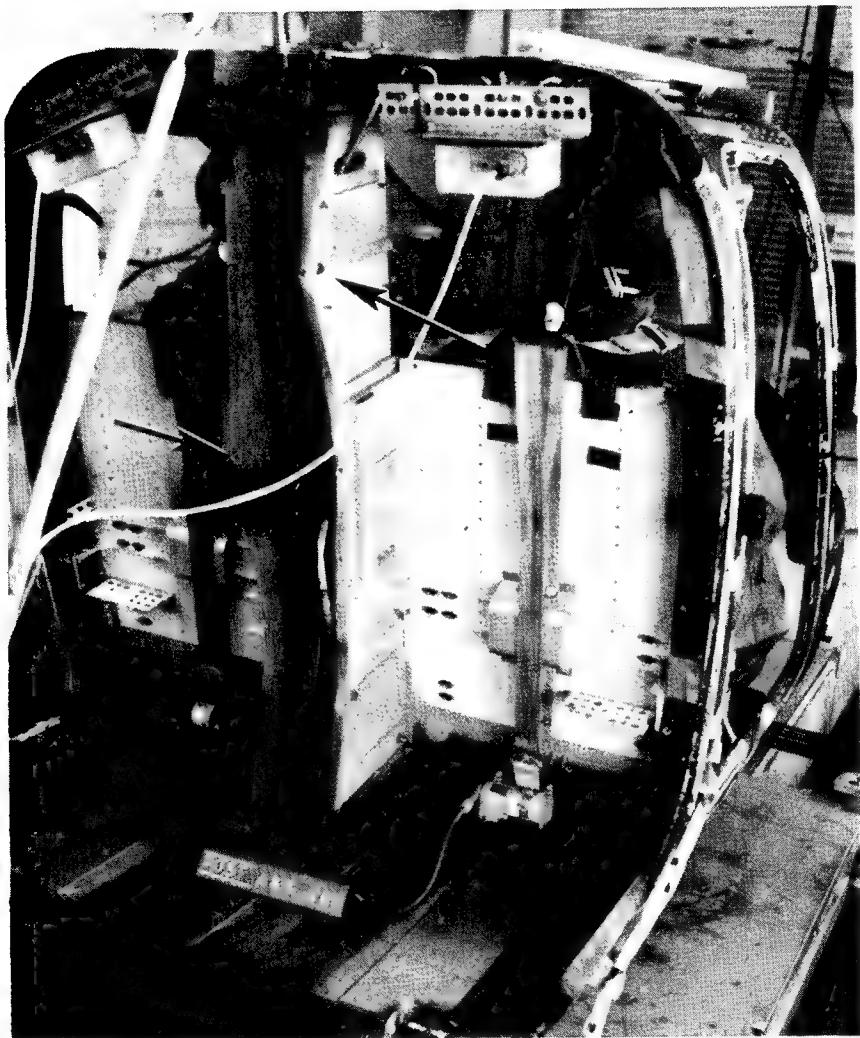


Figure 18. Posttest view of fuselage station 73.04 bulkhead; note buckles in control closet structure by arrows.

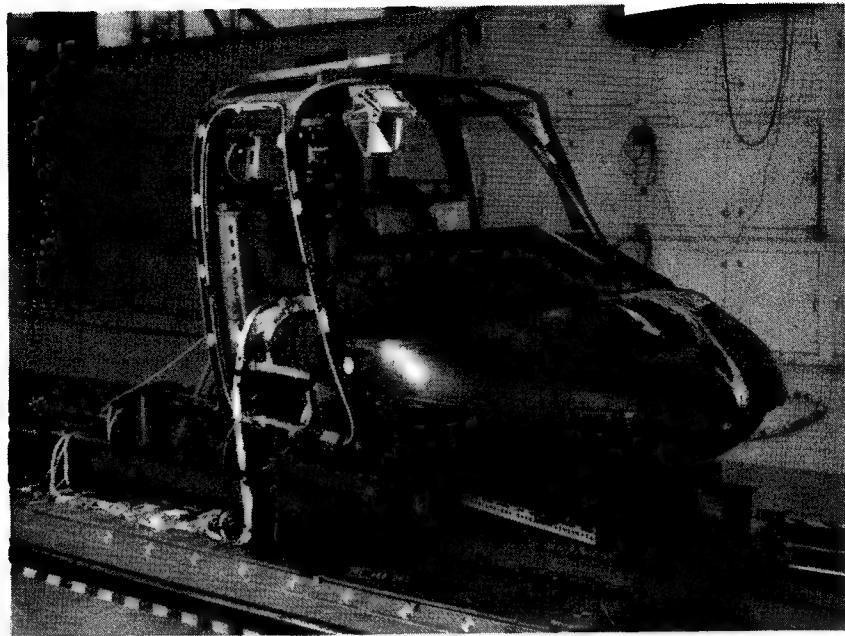


Figure 19. Pretest view of no. 88063; note 15-degree right yaw orientation, and prior damage to nose structure.

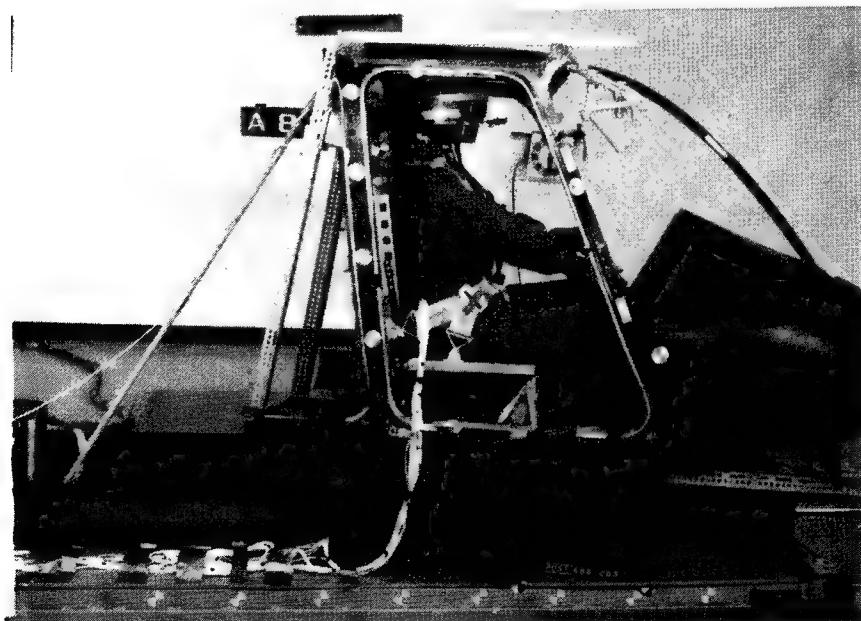


Figure 20. Posttest view of no. 88063; note the actual production PDU mount in place and bulkhead 73.04 reinforcement.

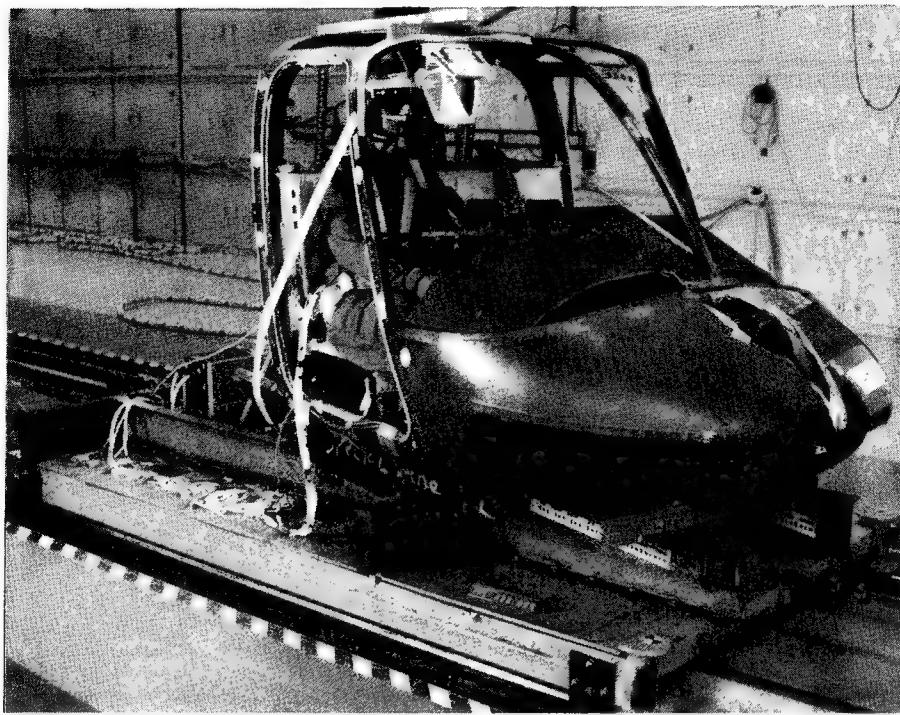


Figure 21. Pretest view of no. 88064; note diagonal aluminum strap added to prevent forward movement of upper door post.

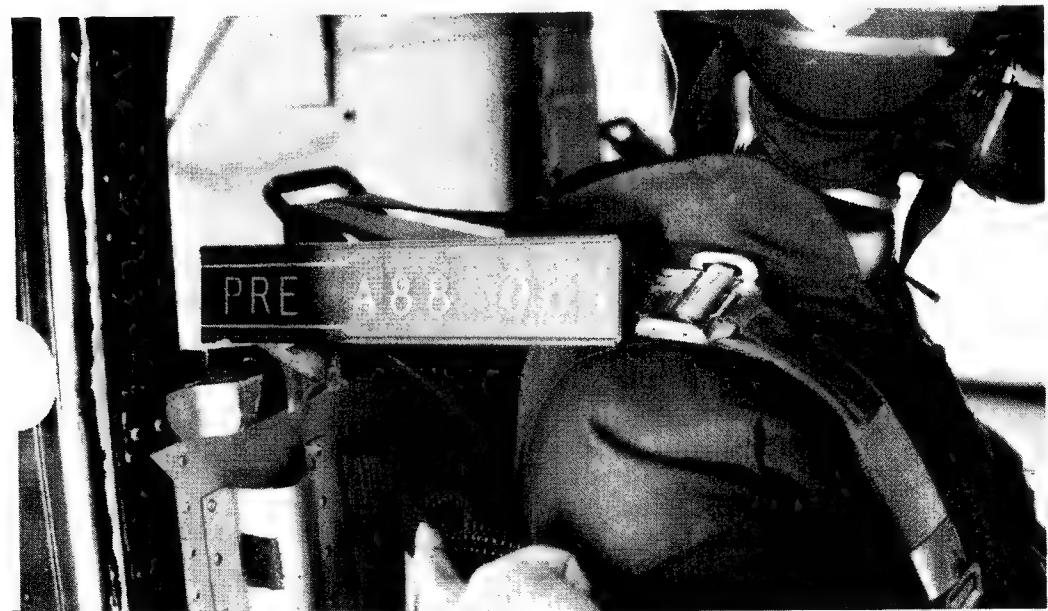


Figure 22. Pretest view of no. 88064; note board behind back cushion to move dummy forward 1.5 inch.

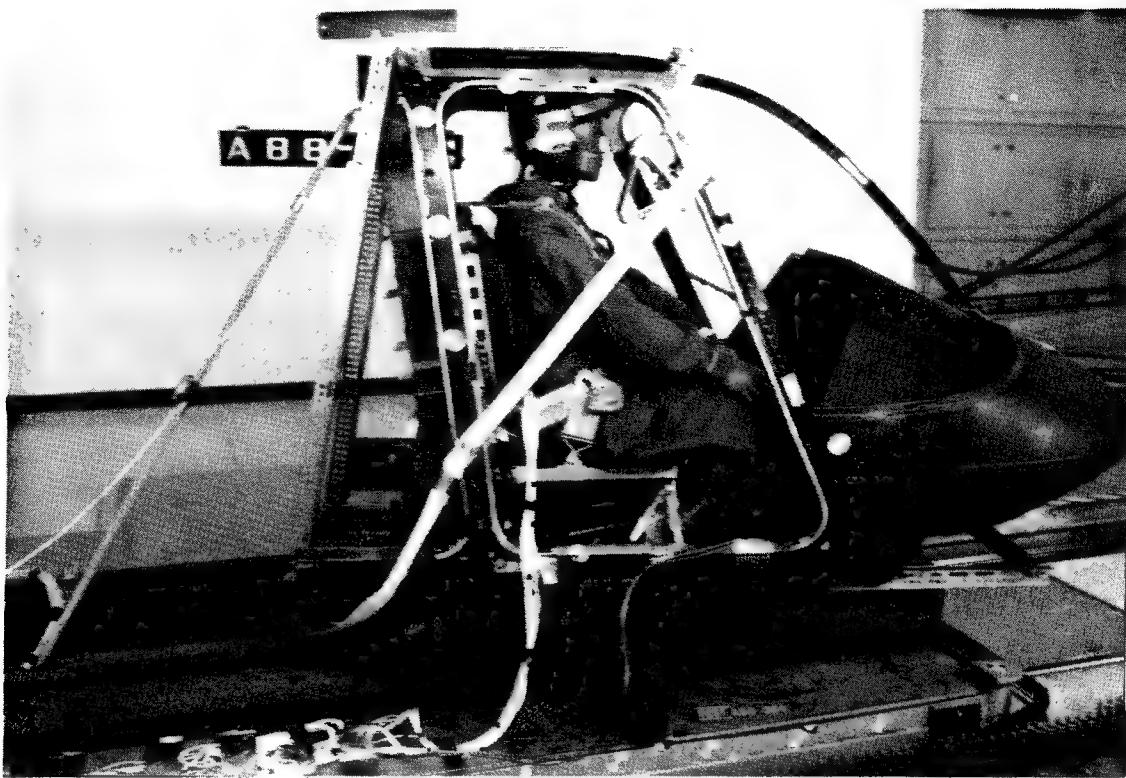


Figure 23. Posttest view of no. 88064; note limp, stretched aluminum diagonal strap, and PDU mount detachment.



Figure 24. Posttest view of no. 88064; note detached PDU "breakaway" mount and cracked foam at back edge of PDU.



Figure 25. Posttest view of no. 88064; arrow denotes cracked helmet visor cover.

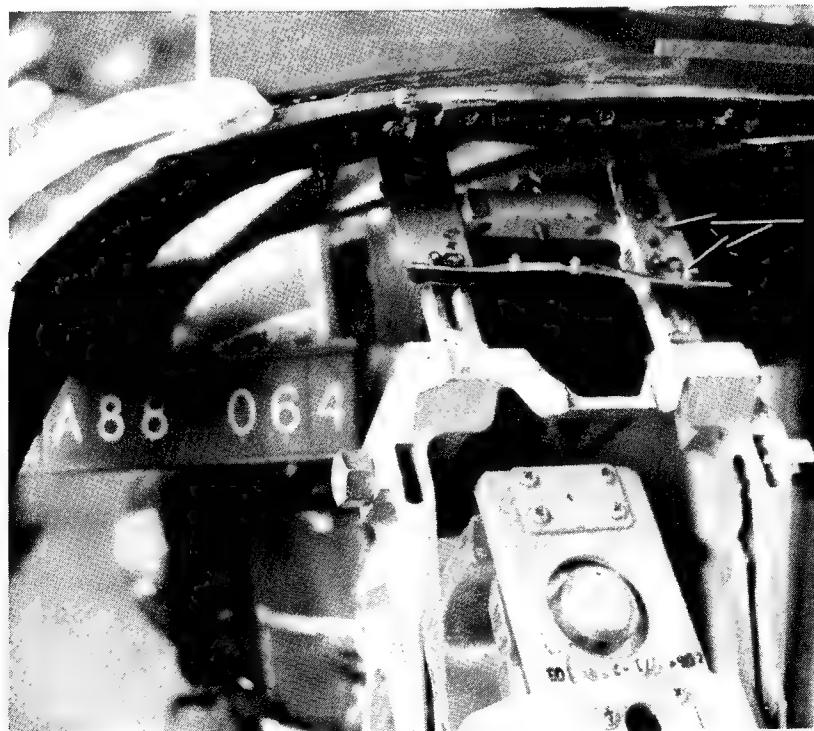


Figure 26. Posttest view of no. 88064; arrow denotes failed rivets which help to secure the PDU breakaway mount.

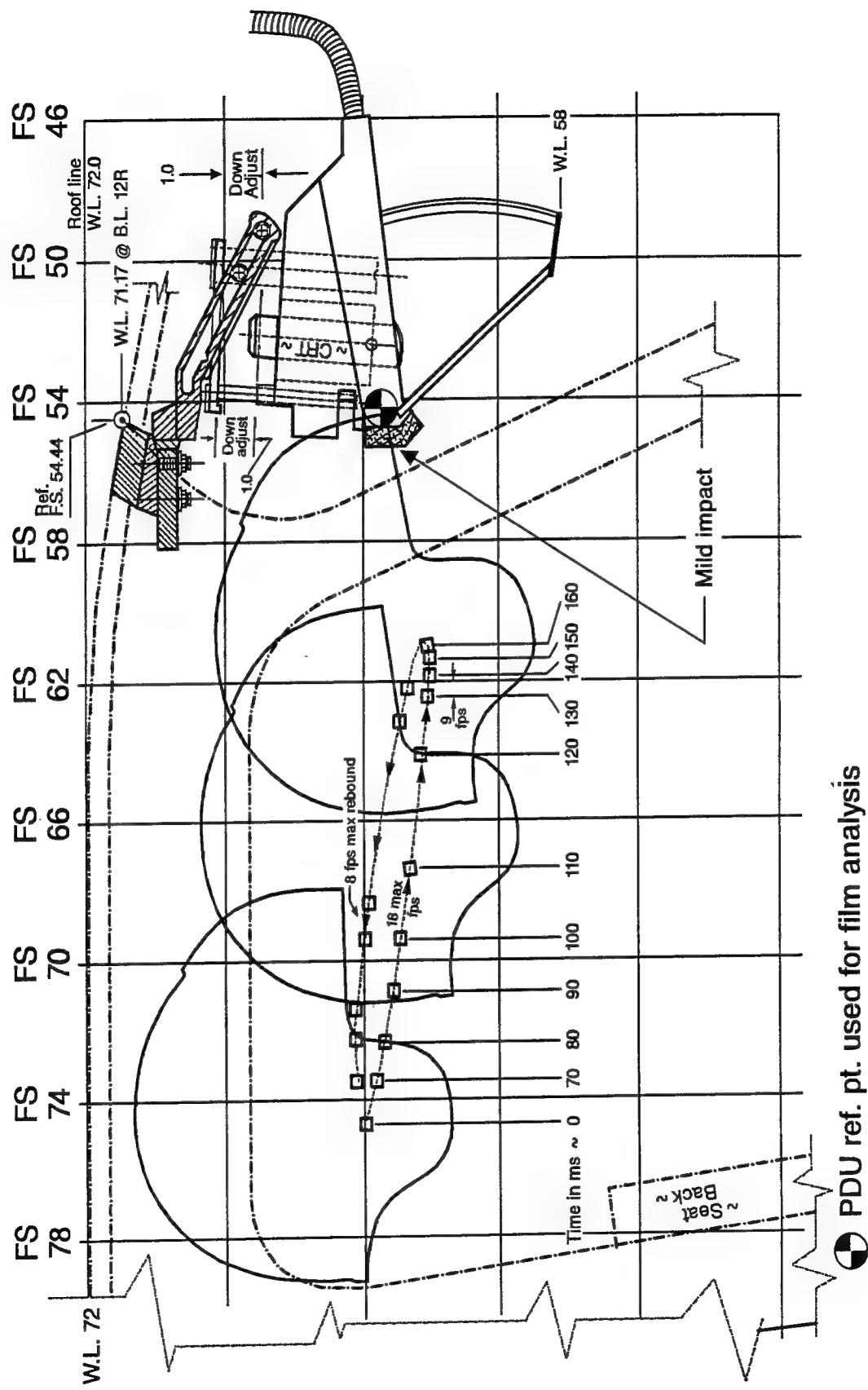


Figure 27. Helmeted head displacement in 30-degree pitch down test 88060.

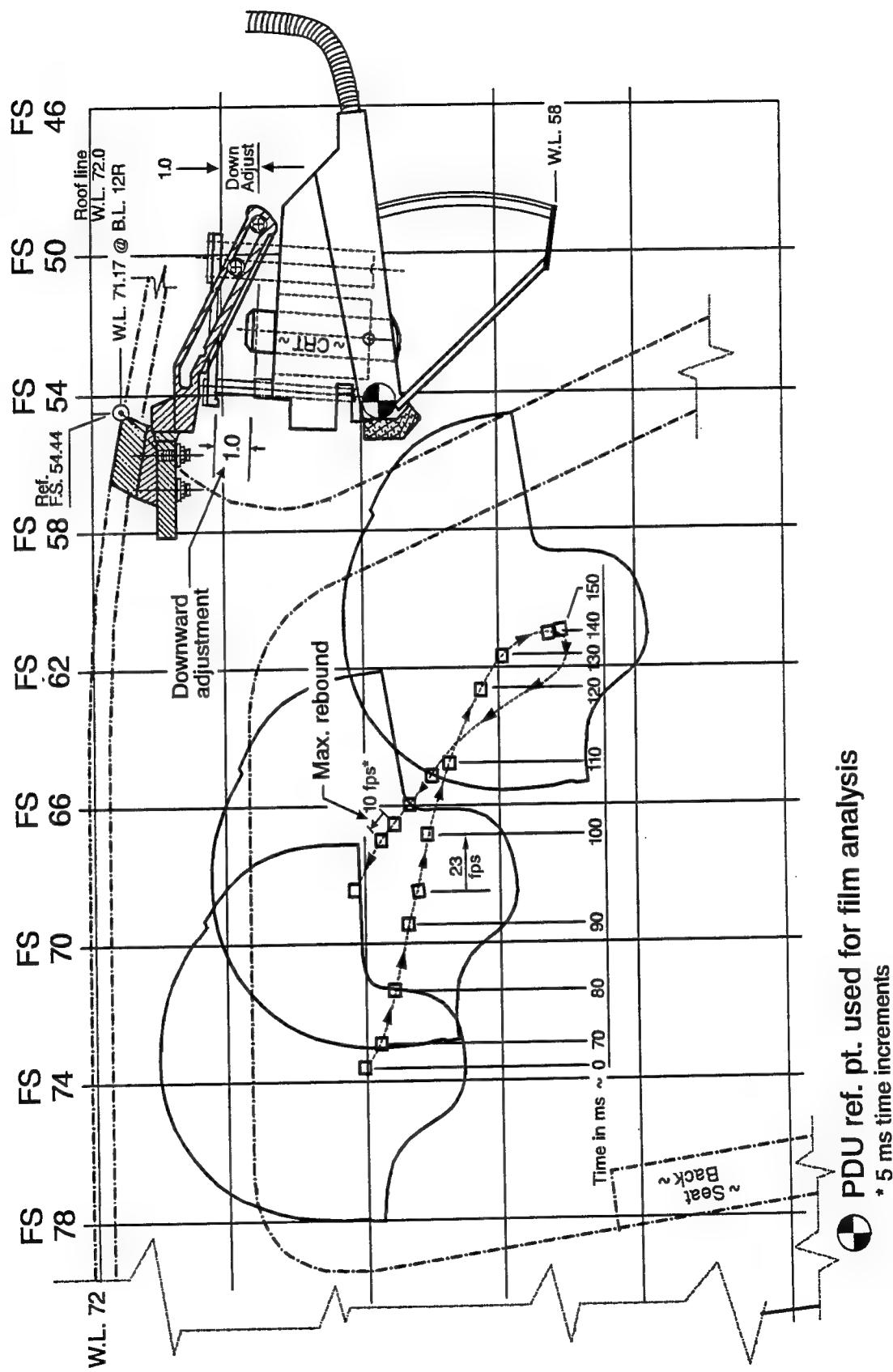


Figure 28. Helmeted head displacement in second 30-degree pitch down test 88061.

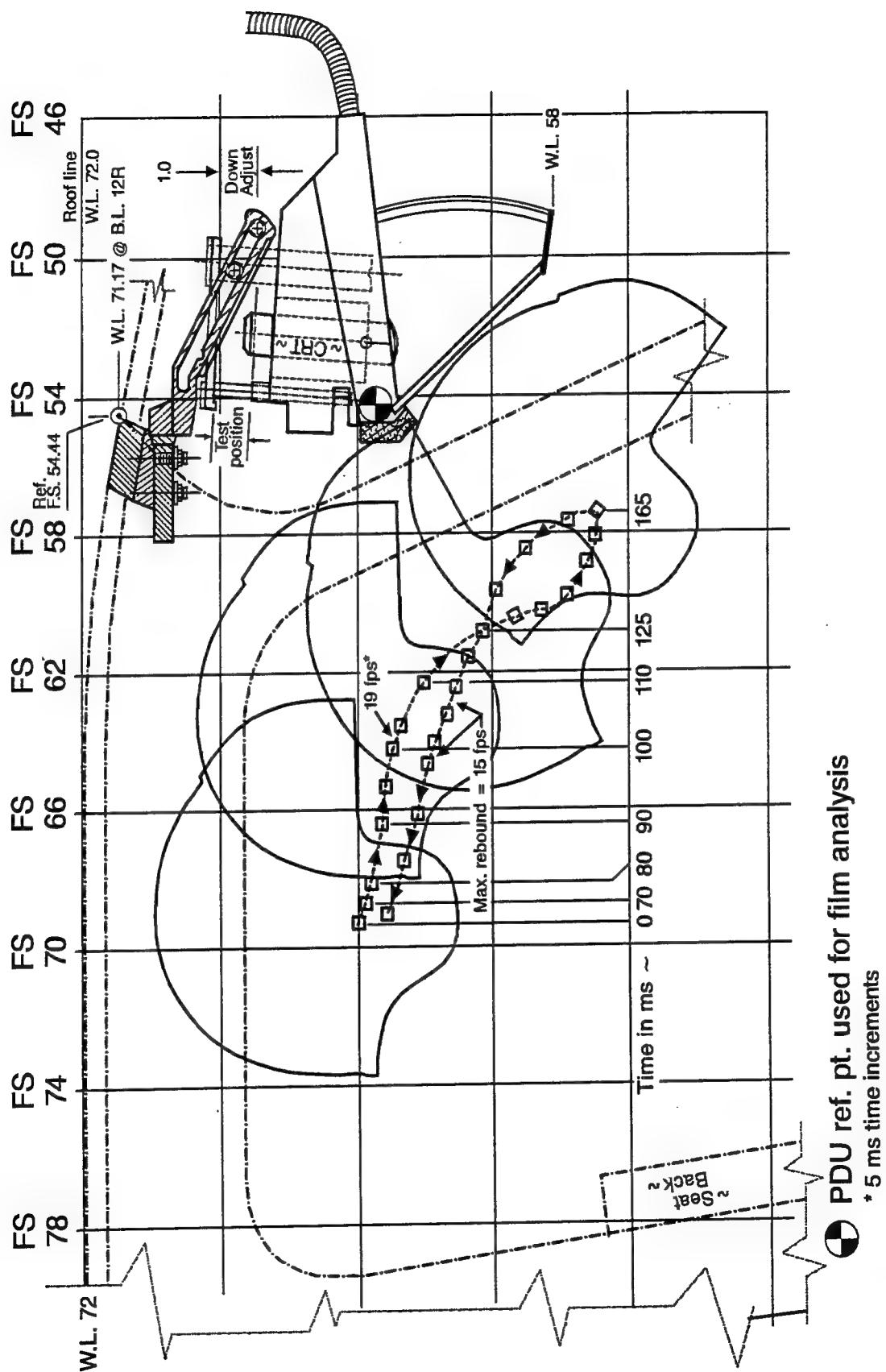
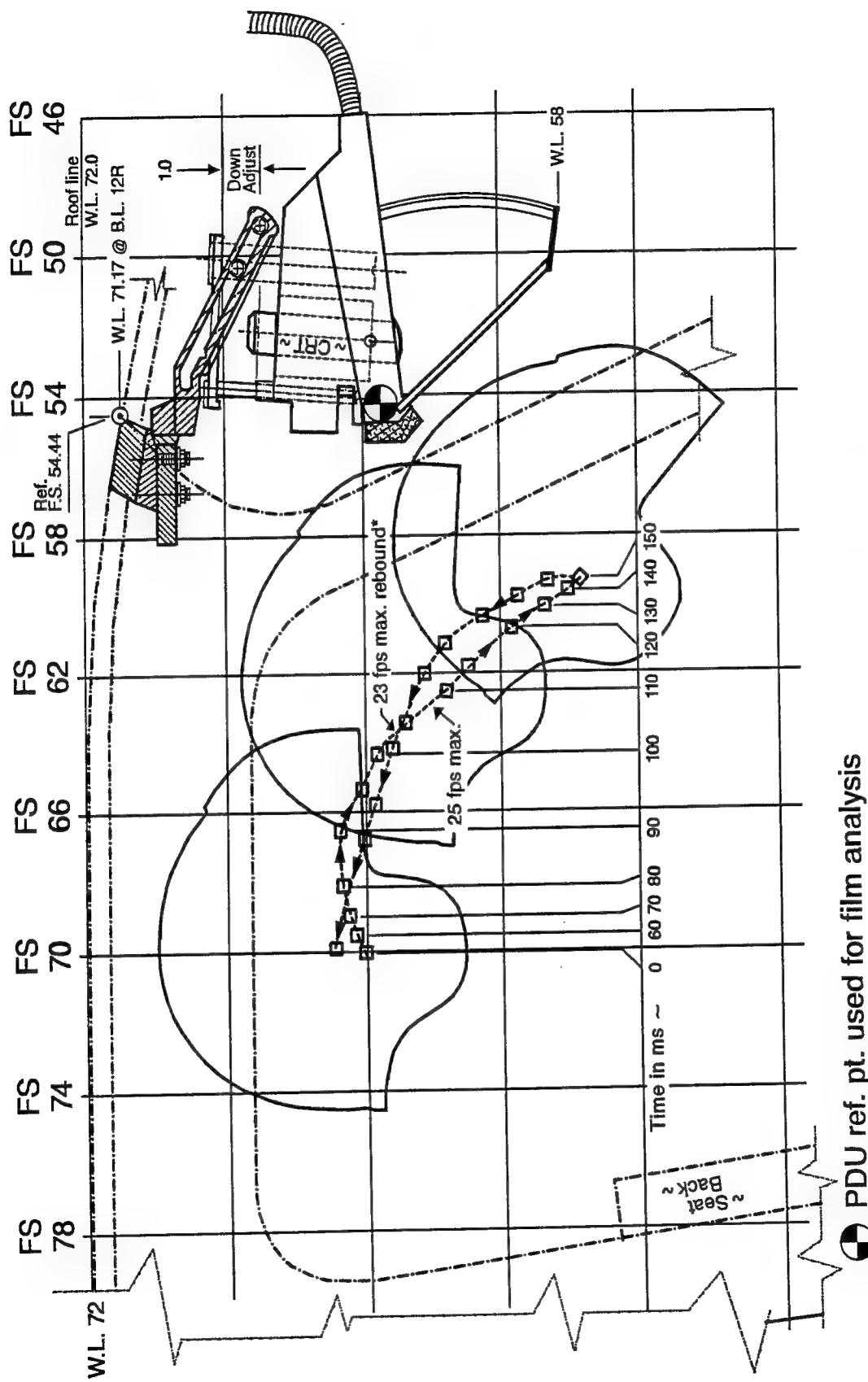


Figure 29. Helmeted head displacement in horizontal (x-axis) test 88062.

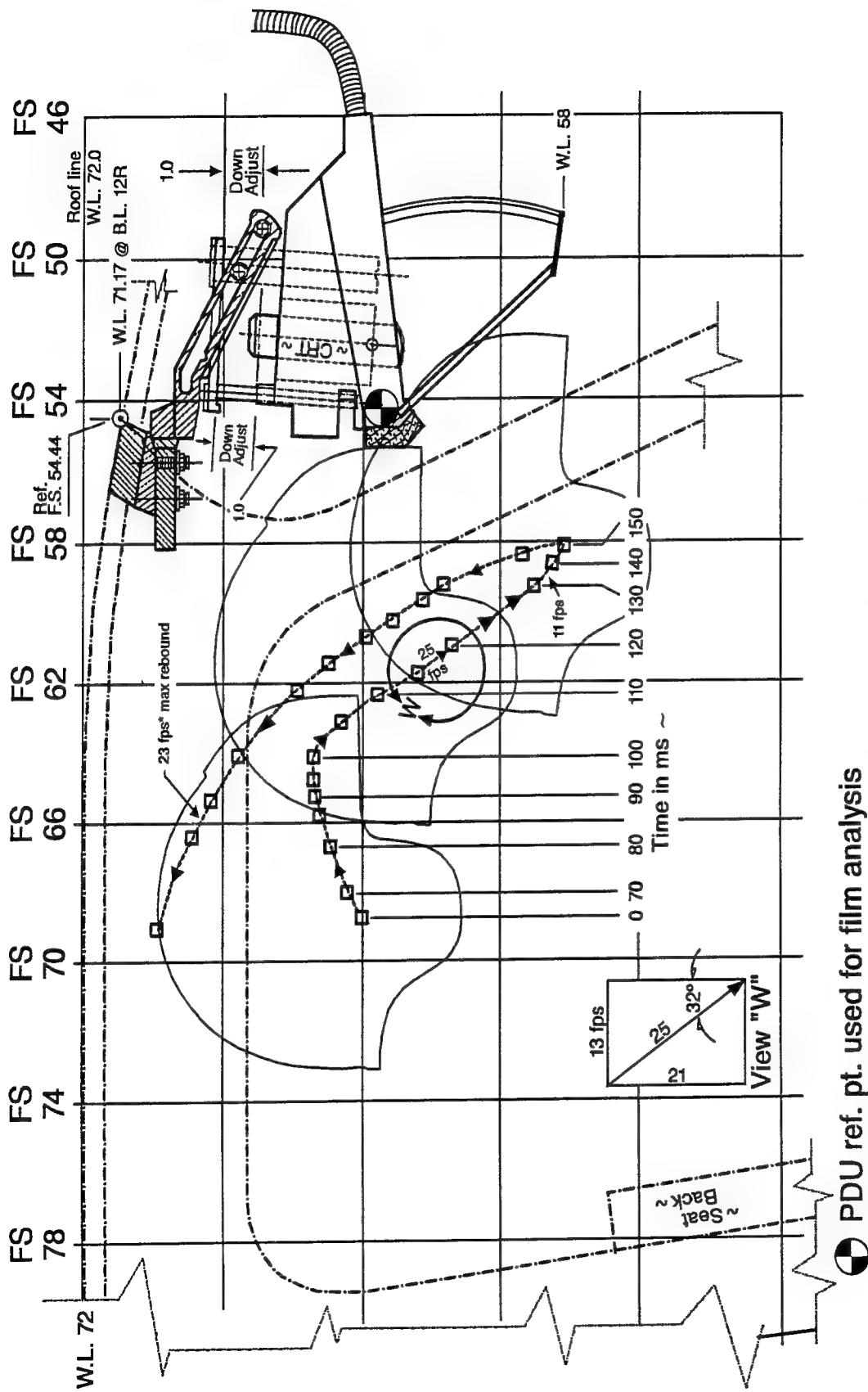


● PDU ref. pt. used for film analysis

* 5 ms time increments

Notes: (1) PDU shown in "breakaway" position, but was located in the rear IN-USE position at time zero.
 (2) Displacement along X-axis was found by correcting calculated distance
 from film analysis by the cosine of the 15° yaw angle.

Figure 30. Helmeted head displacement in x-axis, 15-degree yaw, test 88063.



 PDU ref. pt. used for film analysis

* 5 ms time increments

Notes: (1) PDU shown in "breakaway" position, but was located in the rear IN-USE position at time zero.
 (2) Displacement along X-axis was found by correcting calculated distance
 from film analysis by the cosine of the 15° yaw angle.

Figure 31. Helmeted head displacement in horizontal (x-axis) with 15-degree right yaw, test 88064.

Appendix A.

**Pilot display unit transducer results for
tests 88060, 88061, 88062, 88063, and 88064.**

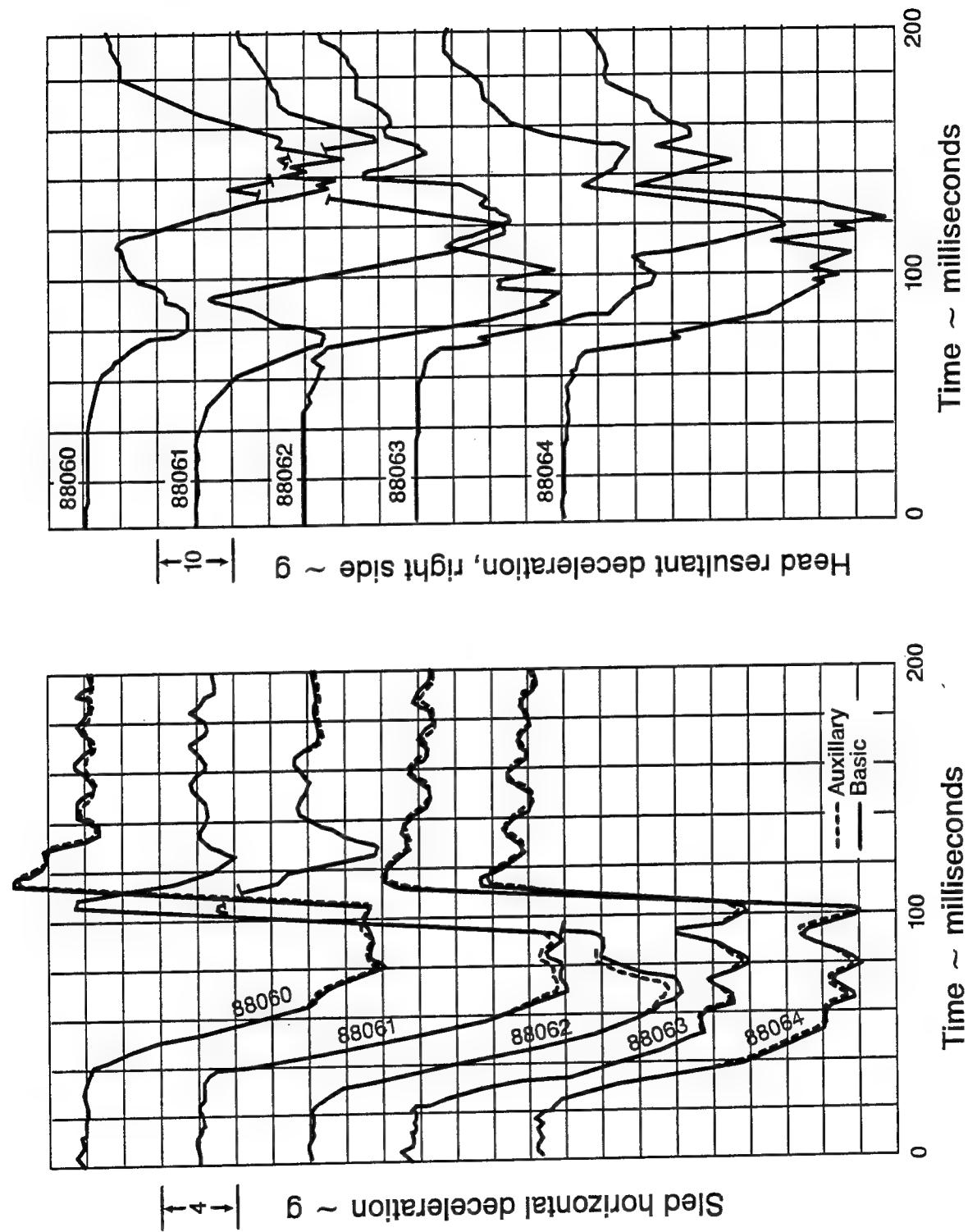


Figure A-1. Sled and right seat dummy head deceleration traces from five PDU tests.

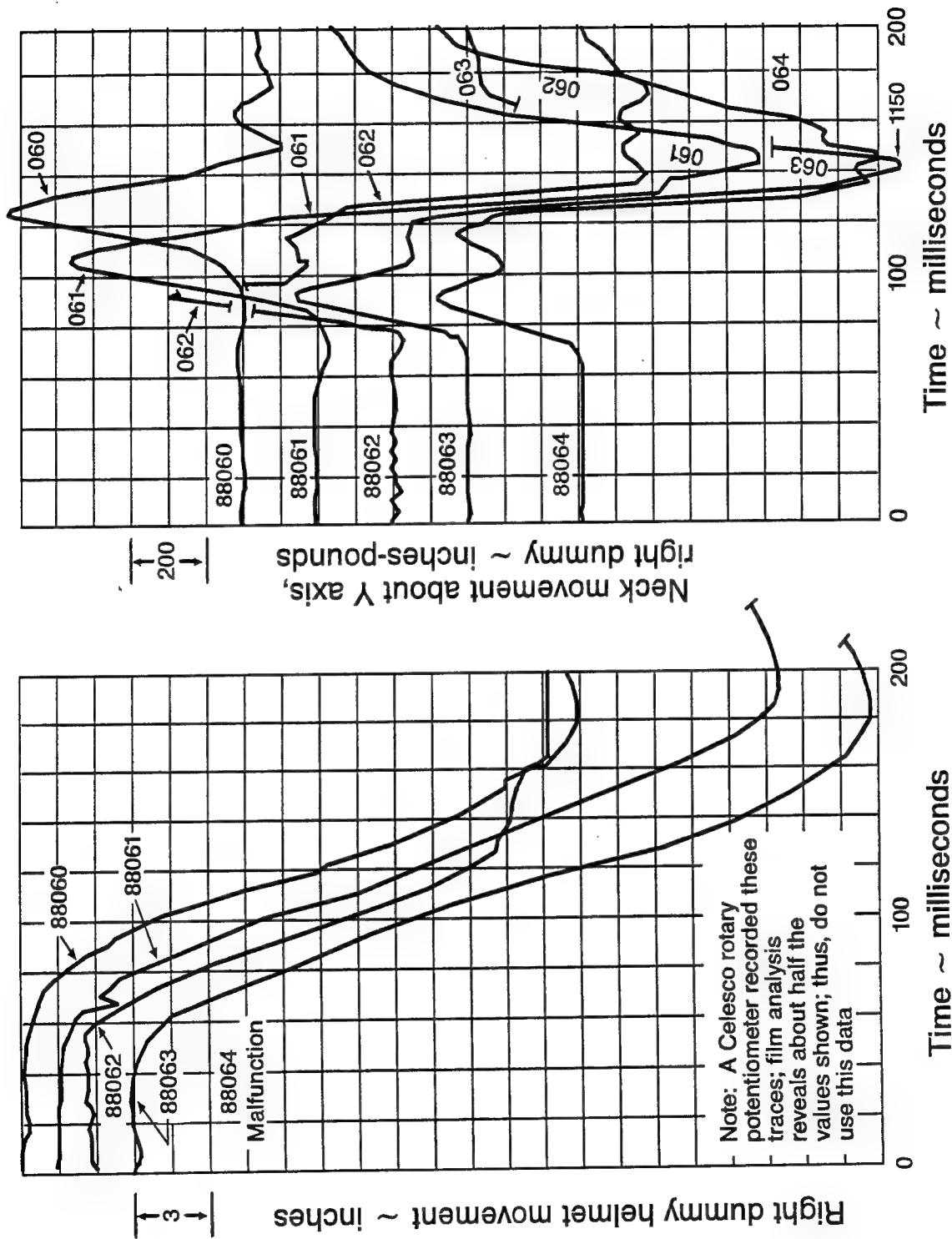


Figure A-2. Right dummy helmet displacement and neck moment about the y-axis for five PDU tests.

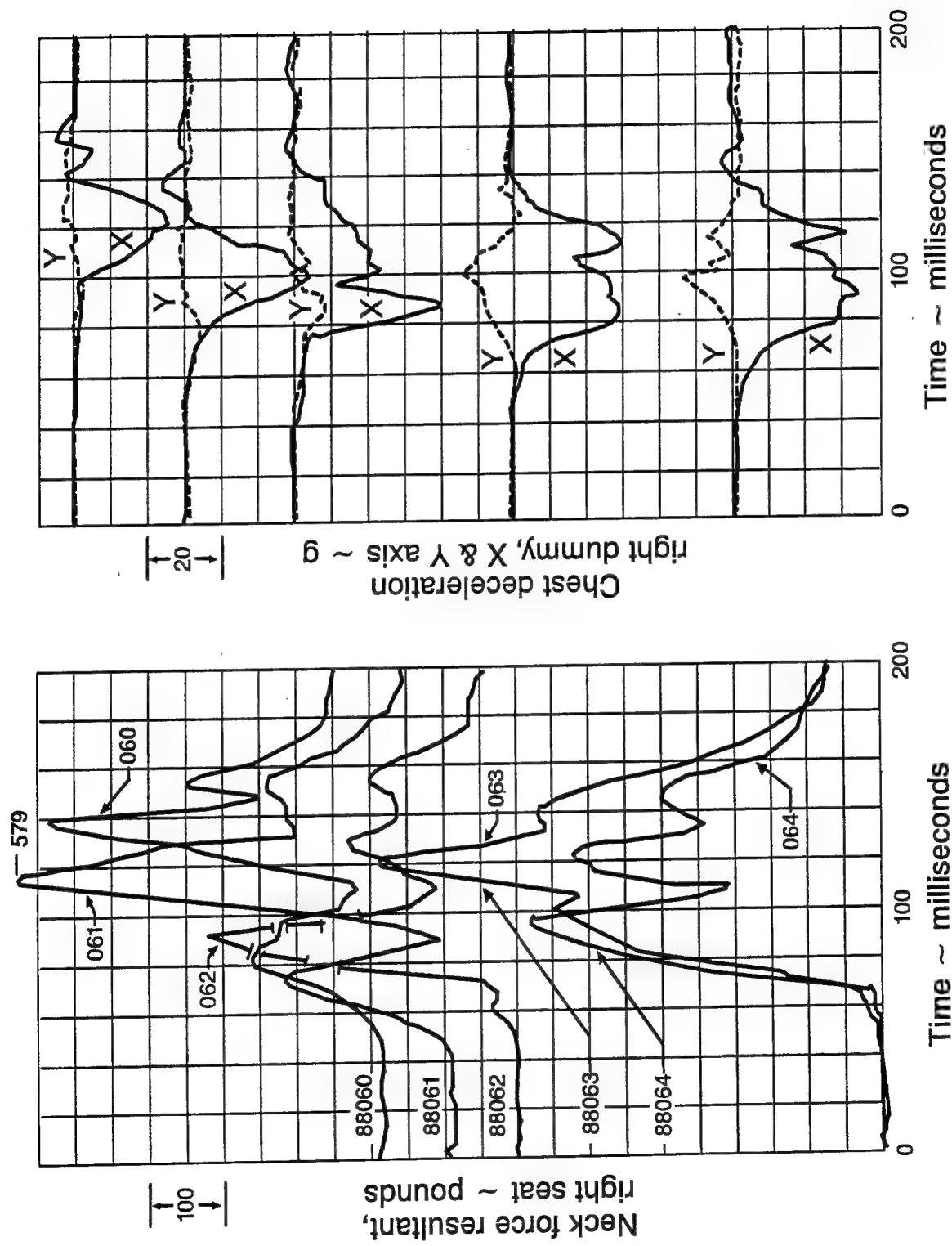


Figure A-3. Right dummy neck force and chest deceleration for all five PDU tests.

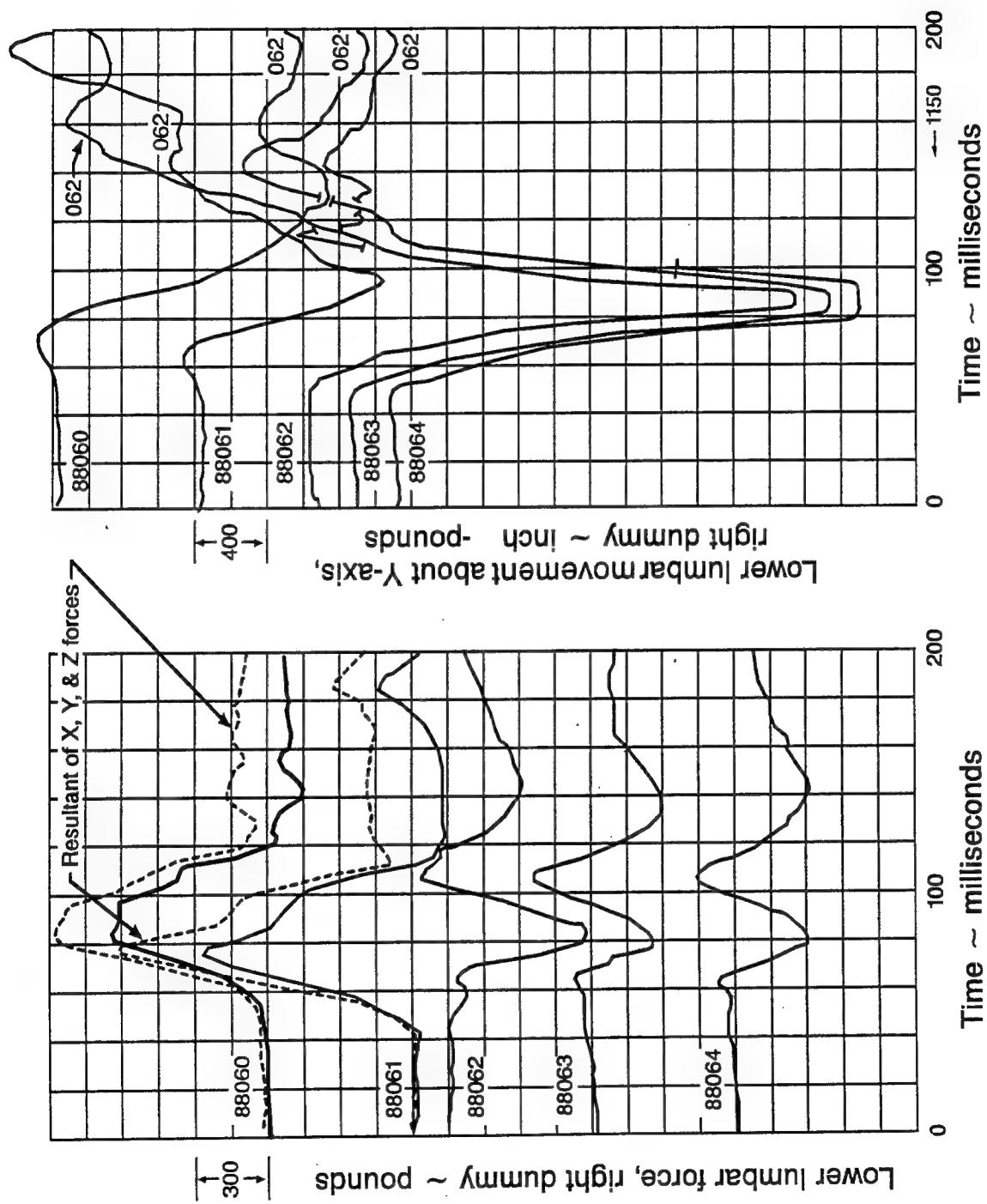


Figure A-4. Lumbar force and moment traces for all PDU tests.

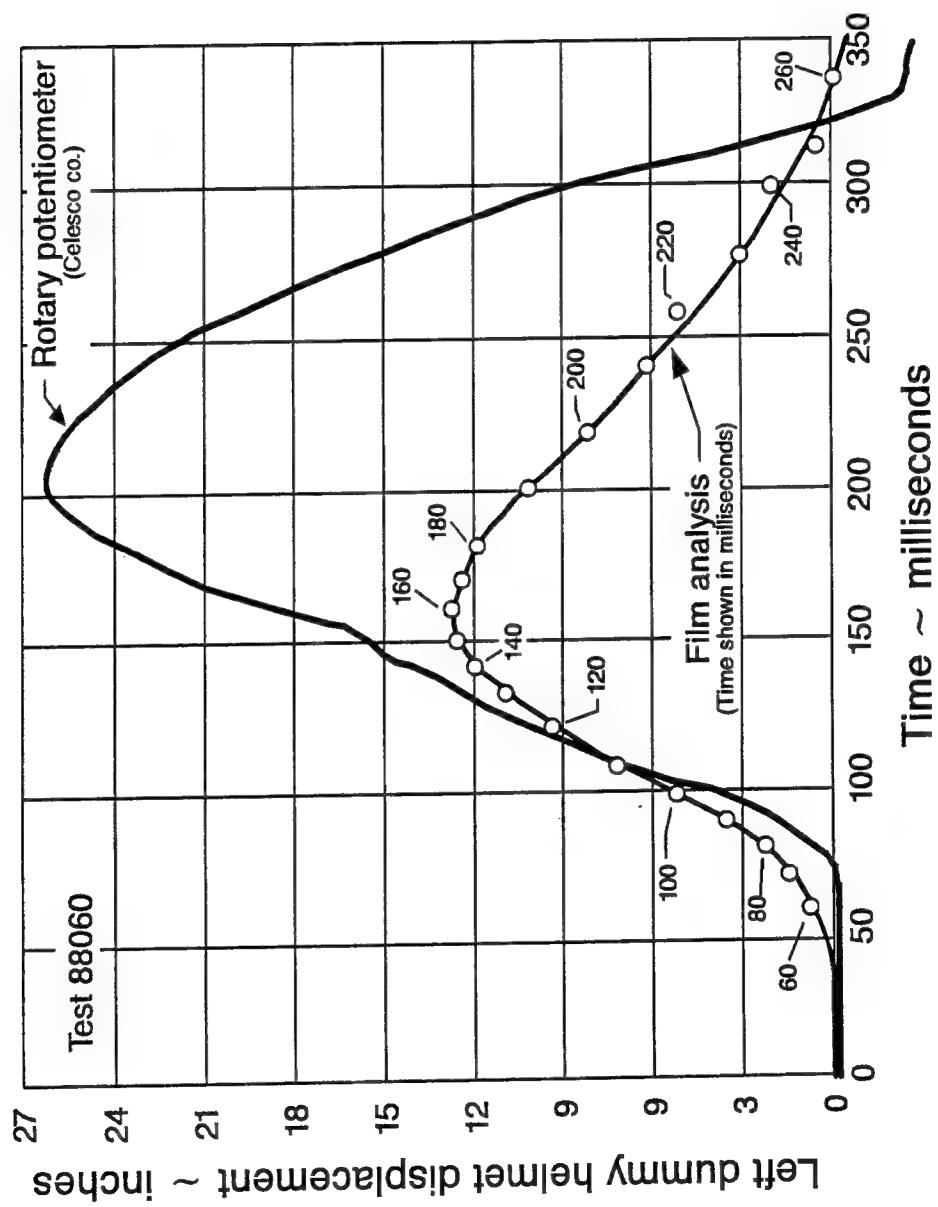


Figure A-5. Comparison of left dummy helmet displacement in test 88060: rotary potentiometer vs. film analysis.

Appendix B.

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